Space Sciences Laboratory
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Final Report on

SPACE PHYSIOLOGY

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Final Report on

SPACE PHYSIOLOGY

NAS 2-1357
NsG 139-61

Instrumentation for the sensing and telemetering of physiological information from unrestrained animals has been developed. Parameters which have been monitored are: blood pressure, temperature, acceleration (a gross measure of motion), respiration, and the electrical signals associated with the heart beat and brain activity. Sensor-transmitter units have been chronically implanted in rabbits, dogs and monkeys. Methods of implantation and the effect of the implants on the animals have been studied. Initial work has been done on a blood oxygen tention transducer to be implanted in a vessel or in the heart.

Most of our work has been on the measurement of blood pressure. Our method attempts to measure blood pressure through the intact artery wall. It is theoretically possible to measure absolute pressure in this way if the wall is flattened and if mechanical motion of the transducer is negligible. Studies on rabbits and dogs indicate that an artery will tolerate application of the transducer and its holder. Transducer-transmitter units have been implanted and have functioned in dogs for periods of several weeks. Problems of drift, moisture penetration and temperature sensitivity are now being eliminated and pressure sensitivity is being increased.

The blood pressure transducer-transmitter has been used, in a modified form, as a respiration monitor. Implanted in the chest cavity, it gives a semi-quantitative measure of respiration.

In electrocardiogram and electrocorticogram units, electrical signals are picked up, amplified and used to modulate a transmitter. These units are designed to transmit continuously for two years and have been used very successfully in animals.

The temperature transducer has also been designed to transmit for two years. This unit and an EKG unit are being tested in monkeys by a group at Ames Research Center.

The following publications have appeared or will appear: "Radio Telemetry From Inside The Body", New Scientist, September 26, 1963.
"The Magnetic Field Associated With Nerve Activity", (submitted to Science).

Further details of the work done in this project are in the two progress reports and the detailed description of the temperature transmitter as follows:

Quarterly Progress Report -- November 1, 1963

Testing of blood pressure, EKG, and temperature units and of their component parts is being pursued.

A chamber has been set up in which blood pressure units are being tested. Temperature and pressure are being varied independently. It has been found that the radio frequency transmitted by the units drops when they are soaked in saline. This drop is very rapid for the first few days and slows to the equivalent of 10 to 30 mm Hg/day. Sensitivity of the units decreases by 25 percent in 5 days. An increase in temperature causes an apparent increase in pressure of 5 to 50 mm Hg/^{o}C in the units being tested. Hysteresis has been found in the pressure curves. After increasing the pressure to 300 mm, error in the readings immediately following is as much as 10 mm. When pressure is varied between 60-140, a probable pulse pressure range, readings are reproducible. The blood pressure units are reasonably stable over periods of from 4 to 6 hours, but daily calibration is required.

Various tests are being conducted to determine the changes, due to temperature variations, in the frequency determining components of the blood pressure transducer. It is possible, with proper selection of components, to balance these changes, and to produce a blood pressure unit with negligible temperature drift. This may be beyond our capabilities, as components with the proper temperature and size characteristics may not be available.

A revised version of the single unit blood pressure transducer-transmitter is nearing completion. Primary considerations involved in the design of the new single unit are size, an increase in sensitivity to pressure, and a decrease in moisture permeability. Preliminary tests indicate that this unit will approach the size requirements for such a device.

As recent tests indicate that the present method of encapsulating the transducer-transmitter is not adequate to prevent water absorption, we have, in connection with the work being done, been investigating means to eliminate the water hazard.

A temperature unit was calibrated and showed an almost linear response to temperature changes. It was stable over the four day test period. Four more units are being constructed to complete the testing of the temperature monitor.

Animal instrumentation needs for the NASA Bio-Satellite Project were discussed with project personnel at Ames. They plan to place an instrumented Rhesus or Pig-tailed monkey in orbit and to monitor the animal's EKG, respiration, blood flow, blood pressure and temperature. This will take place towards the end of '64 or the beginning of '65. The tentative decision of the Bio-Satellite group, based on current availability of instrumentation, is to use a hard-wired system, but they would prefer to use a telemetered system, if such were available.

Our temperature and EKG monitors seem to meet adequately the needs of their projects and are being tested. These units have been implanted in a monkey by the Bio-Satellite group at Ames, and will be included in a centrifuge experiment, in November.

The telemetering of blood flow and of blood pressure information is an unsolved problem. In its present state our blood pressure unit will not satisfy the project's requirements. Ames, however, is much interested in its possibilities, and would like to test the unit, even in its present state.

Some interest was also expressed in an intrathoracic pressure transducer, a device with which we have had some experience. Preliminary studies, based upon Ames needs and our previous experience, have been started.

Progress Summary -- December 1963

The single unit blood pressure transducer-transmitter is being modified to increase the stability of its circuits and to improve its capability in measuring pressures. Mechanical motion of the transducer diaphragm will be severely limited. This makes possible a very close approximation to true pressure measurement and will decrease errors caused by changes in the arterial wall. This change in the transducer will make it necessary to increase the sensitivity of the sensing element.

Several test circuits have been built, two of which have been incorporated in units which are now undergoing tests for the efficiency of the present potting and construction techniques. A third circuit, designed by Mr. Jenkinson, has been built and is being tested. Results show that this circuit is capable of providing a stable oscillator, independent of temperature, provided that the coils do not change in inductance as a result of temperature changes.

Tests show that some temperature sensitivity lies in the transducer and transmitter coils. Some work has been started toward possible elimination of the transmitting coil and modification of the transducer coil to eliminate the temperature sensitivity of this component. Transducer-transmitter circuits of continuously transmitting types and blocking types were studied. Various characteristics were observed among the many types of oscillators investigated.

Transmitters have been developed which are capable of transmitting three different types of data simultaneously with very low power. A series of measurements was made in a 65,000 gallon salt water tank to test the effectiveness of low level signals through walt water. The feasibility of telemetering from diving mammals and from fishes was demonstrated. The transmitted signals could be received at distances up to 50 feet. These measurements also further elucidated the manner in which signals are transmitted through an animal's tissues. Associated with this work was the investigation of a new type of transmitting antenna which consists of an insulated dipole with conducting end electrodes. This proved considerably more efficient than the loop (magnetic dipole) antenna which has previously been almost universally used.

In collaboration with a group at Oak Knoll, swallowable pressure transducers were used to study the peristaltic patterns in human beings. Mr. Harvey Fishman has succeeded in detecting the magnetic field induced as an impulse and propagated along a nerve bundle. By using a calibrated amplification system, he was able to make the first estimation of the magnitude of this field. It was found to be several hundred microgauss. Two review articles on the subject of telemetry have been prepared.

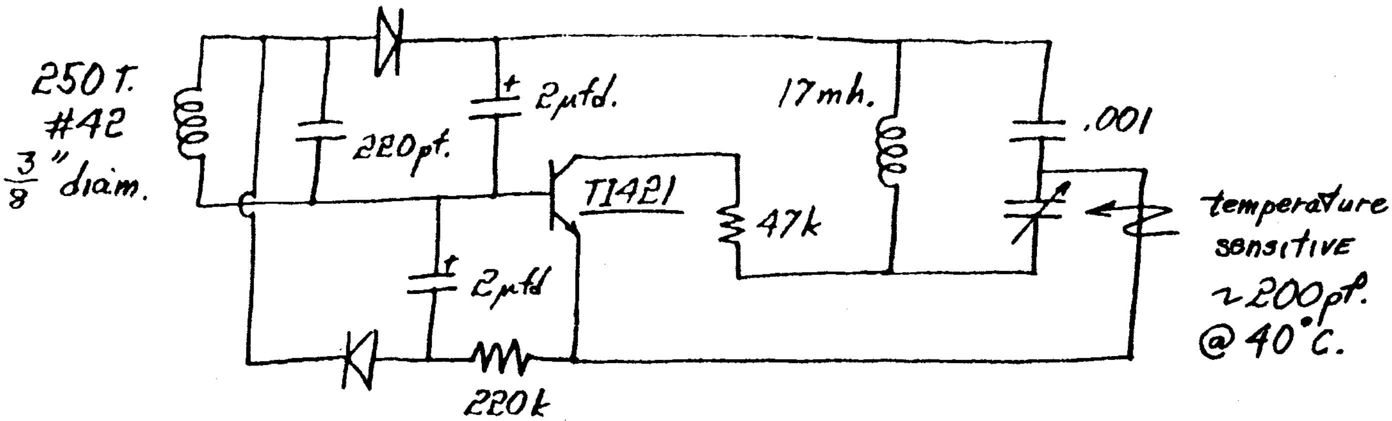
Temperature Transmitter

The first temperature transmitter, constructed in December of 1961, is powered by an external one megacycle induction field, and transmits on a nominal frequency of 100 kc. A temperature sensitive capacitor in the tank circuit of the oscillator causes a frequency deviation of approximately 500 cps/^{o}C (see circuit diagrams figure 1). The design was abandoned because of the excessive bandwidth required and the high cost of fabricating and vacuum encapsulating the capacitor.

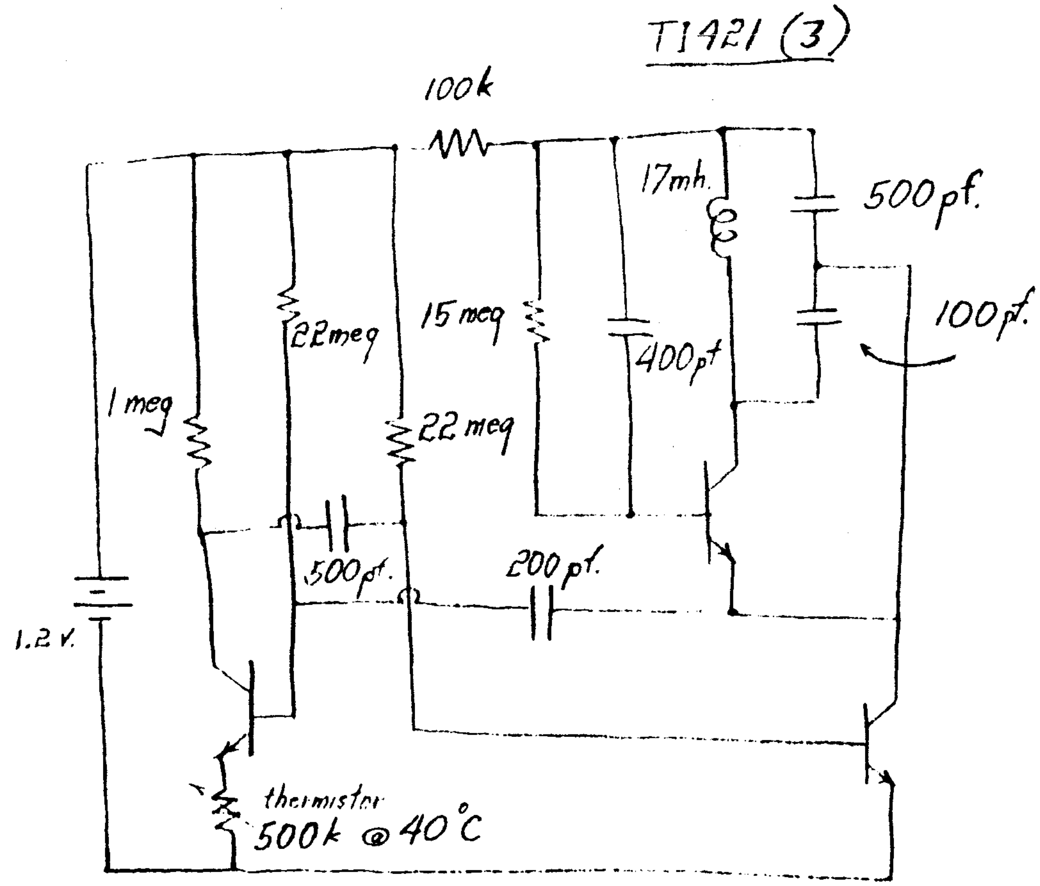
A subsequent design, shown in figure 2, uses a thermistor to sense temperature, and is powered by a hearing aid battery (Mallory No. 312). It employs pulse modulation, (400 c.p.s.) to decrease the bandwidth, but is relatively unstable, due to the presence of the 22 meg. resistors in the multivibrator. (These resistors were commercially unavailable in microminiature versions, and were fabricated in the lab from one watt molded carbon resistors.) Ten megohm hermetically sealed thermistors were employed in the next design (figure 3). The oscillator is switched at two cycles per second, and is isolated from the multivibrator to minimize interaction.

The improved and presently employed version is diagrammed in figure 4. The battery, a silver oxide unit used in electric watches, has very low leakage, constant discharge voltage, and three times the capacity of the formerly used battery, a Mallory No. 312 (it unfortunately occupies three times more volume). The rate of the multivibrator (T1 and T2) is controlled by C1, C2, R2 and R3, each of which has a negative temperature coefficient of about 5 percent/^{o}C at 40^{o}C. The collector loads are thermistors to keep the collector to base current ratios constant, and an inverting stage (R5, T3) provides a low driving impedance to the oscillator.

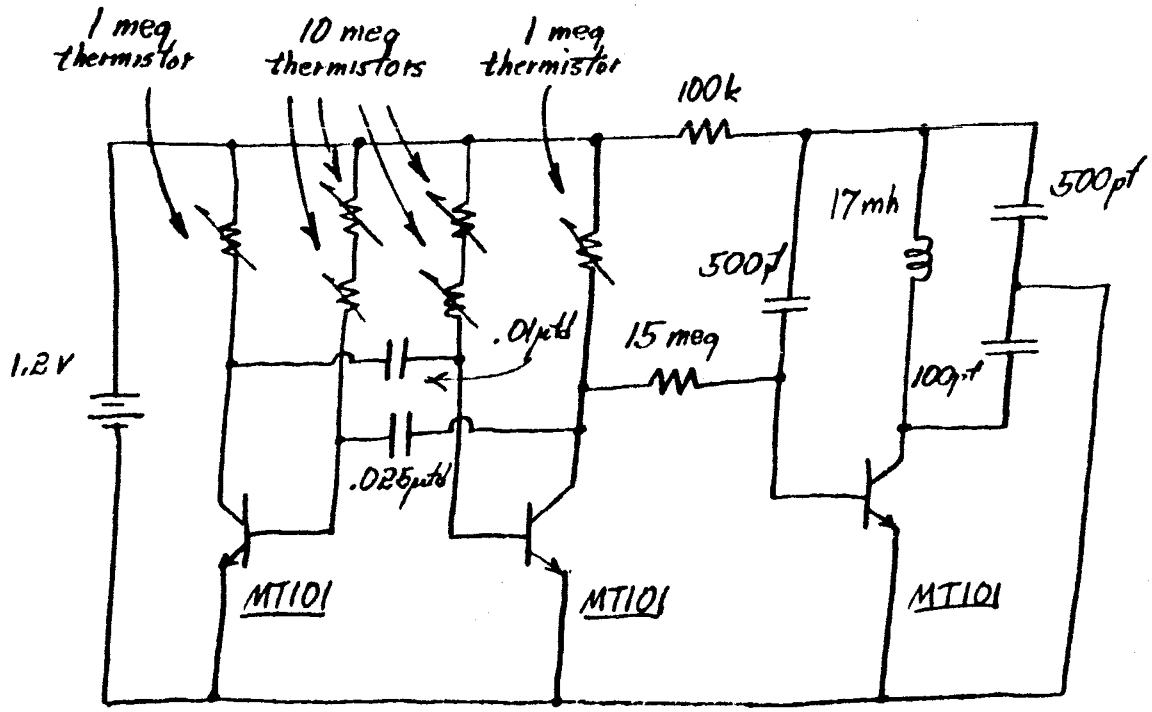
Components are assembled on 10 mil epoxy board and potted in Armstrong C3. The inductor (L1) is wound and potted on the perimeter, and a coating of silastic rubber (Dow Corning No. 502) completes the unit.



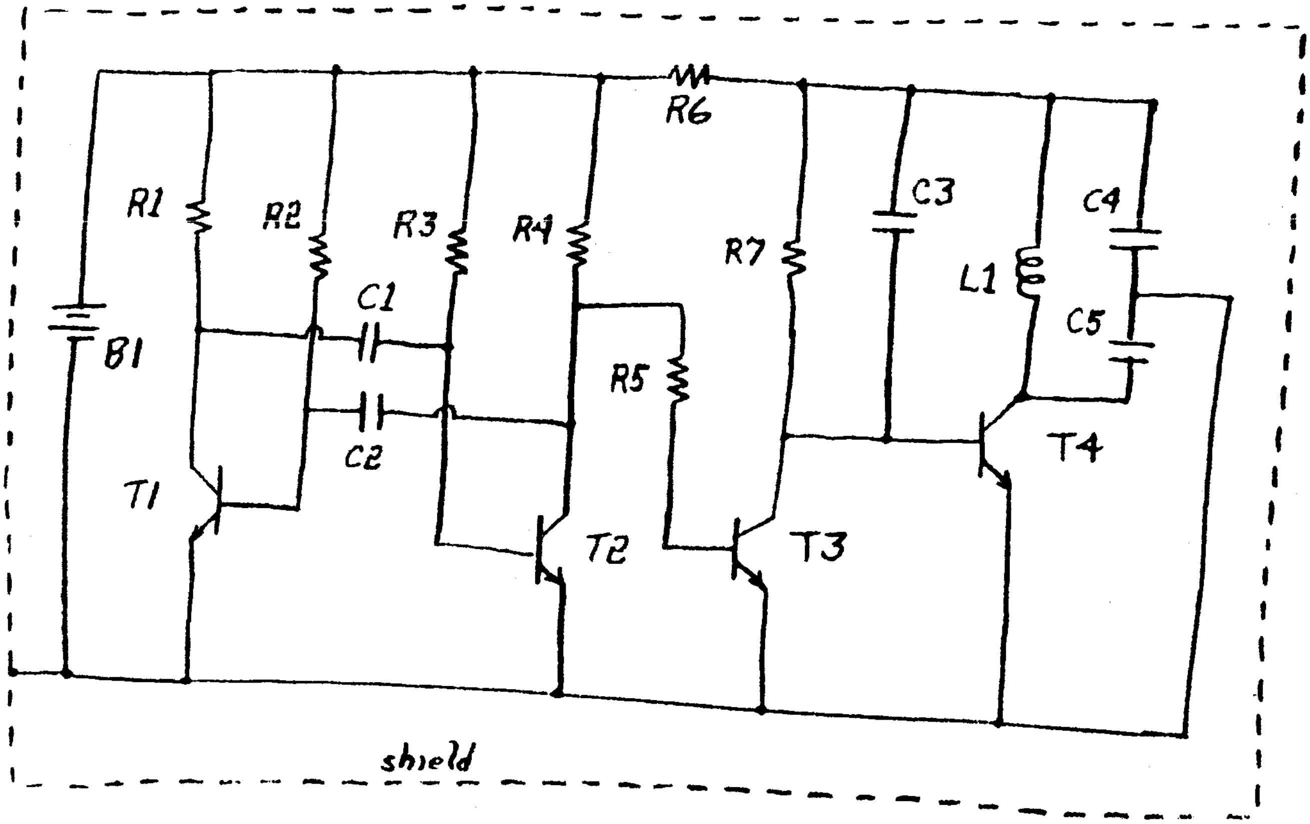
TEMPERATURE
TRANSMITTER
12-61 D.B.



TEMPERATURE
TRANSMITTER
3-62 D.B.



TEMPERATURE
TRANSMITTER
7-62 D.B.



TEMPERATURE
TRANSMITTER
1-15-63
D.B.

PARTS LIST -- TEMPERATURE TRANSMITTER

B1	battery, 1.5 volts, Hamilton No. 505
C1	capacitor, 5000 pf., Gulton No. G-MIN-V-.005-Z
C2	capacitor, 1500 pf., Gulton No. G-MIN-V-.0015-Z
C3, 4	capacitor, 430 pf., Scionics pellet
C5	capacitor, 100 pf., Vitramon No. VK21 CW101
L1	inductor, 500 turns No. 39, see text
R1, 4	thermistor, Fenwal No. GA62J1
R2, 3	thermistor, Gulton No. 71DM10
R5, 7	resistor 5 meg., Mallory No. 6928RP
R6	resistor, 100 k, C. T. S. ceradot
T1, 2, 3, 4	transistor, General Instrument No. MT101, select for low noise

Pressure Transmitter

Several schemes for sensing pressure have been investigated, but as of this writing no single transducer has met all the requirements of the ideal pressure sensor. A table relating the methods investigated and some desirable qualities for biomedical applications appears below.

	Capacitor	Inductor	Resistive Paint	Wire Strain Gauge	Semiconductor Strain Gauge
Size	1	0	3	2	2
Mechanical Impedance	2	1	3	2	2
Measurement Power Required	3	3	1	0	1
Parts Cost	3	3	3	1	1
Fabrication Difficulties	0	1	2	2	2
Zero Drift	1	2	0	2	3
Noise	3	3	0	3	3
Moisture Sensitivity	0	3	1	2	2

Numbers are arranged in order of increasing desirability:

0 Terrible
1 Poor
2 Good
3 Excellent

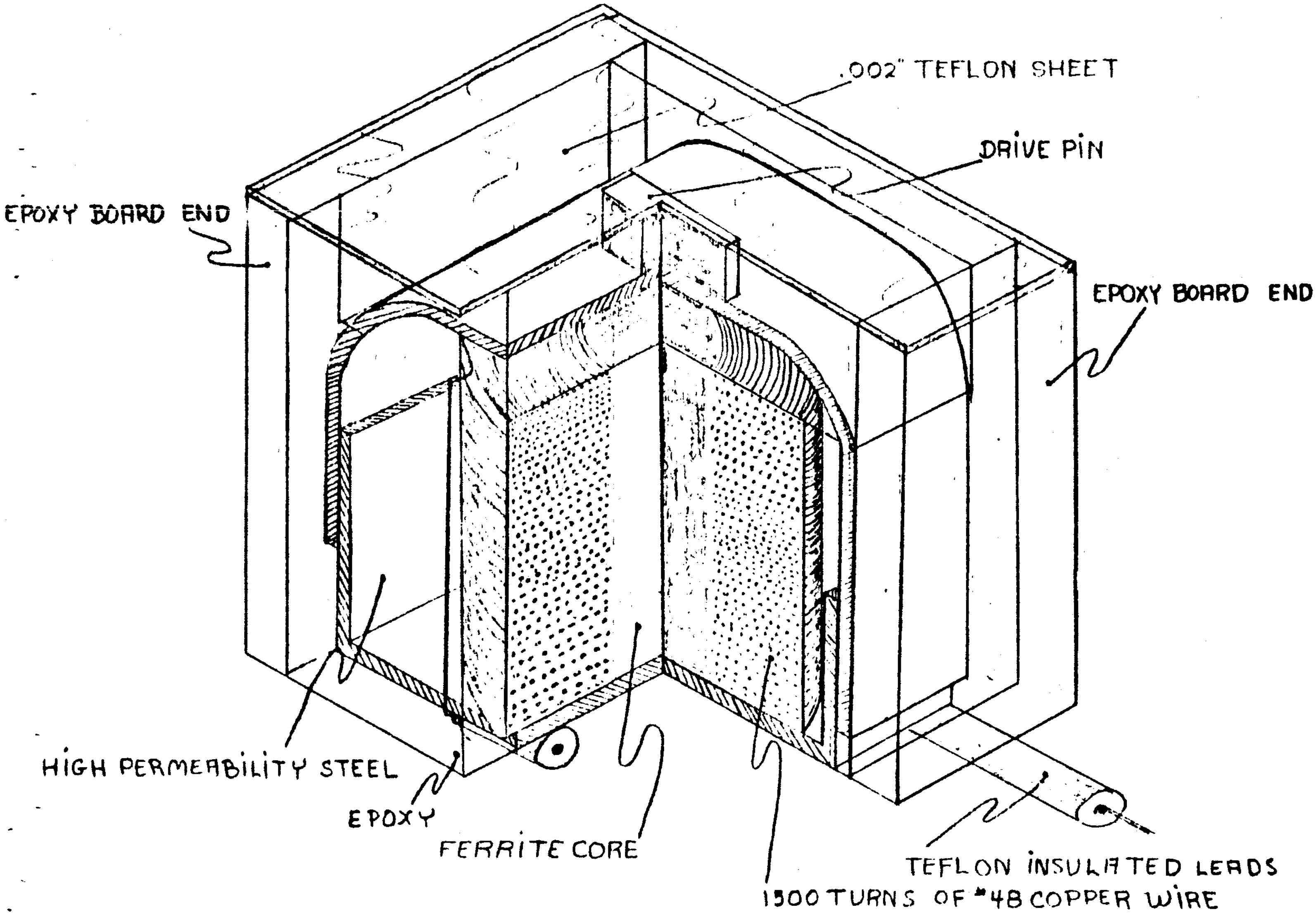
Pressure sensitive capacitors constructed of anodized aluminum plates were incorporated in several successful implants on carotid arteries of rabbits, but all were short-lived due to the transducers' extreme sensitivity to moisture. Pressure sensitive resistive paints were tried with no success; all proved to be very noisy and unstable.

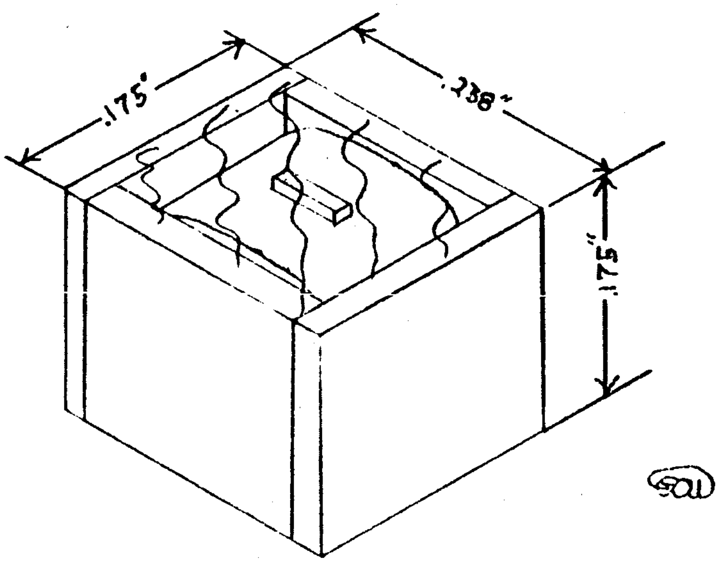
The device currently used to measure pressure consists of a coil wound on a ferrite core and a flexible steel armature surrounding it as shown in figure 5. The assembly is potted in Armstrong C3 and sealed with a teflon membrane. Force applied to the device pin diminishes the air gap between the core and the armature, thus increasing the inductance. The force sensitivity may be as much as 2 percent per gram, while the pressure sensitivity depends on the pin area and tautness of the membrane. The transducer has been used to measure thoracic pressure (figure 6) and blood pressure (figure 7). To measure blood pressure, it is encapsulated in a silicone rubber jacket (figure 8) which is then sutured around the artery, compressing the artery to about 20 percent of its original cross-section.

The sensing of blood pressure through the arterial wall is justified by its simplicity, but it remains to be determined if the method can provide long term accuracy. The present circuitry used to telemeter variations in the inductance is in itself subject to drift, and over a few month's time, the uncertainty in the measurement of absolute pressure is considerable. Pulse pressure, pulse shape, and pulse wave velocity are all derivable from this measurement, are immune to the effects of drift, and might well be significant physiological variables.

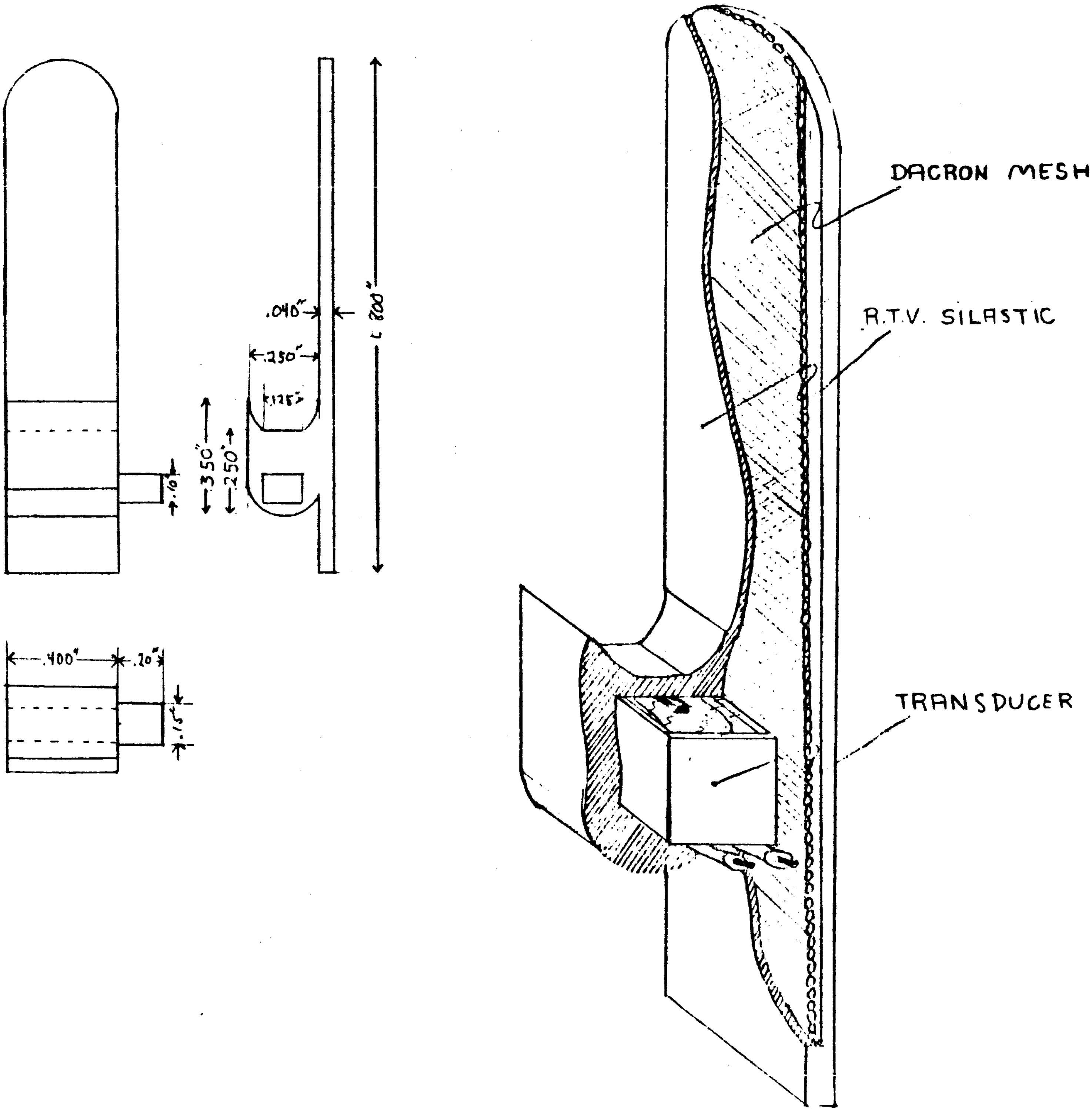
The circuit presently used to transmit blood pressure and thoracic pressure is shown in figure 9. It consists of oscillator T1 and grounded base amplifier T2. L2 is wrapped around the assembly as in the temperature transmitter, and C4 is chosen to tune the tank circuit to the average oscillator frequency. In measuring blood pressure, the circuit is separated at the dotted line to minimize the weight attached to the artery. The thoracic pressure implant is a single unit, with the transducer membrane parallel to the surface. Both units are encapsulated in Armstrong C3 and coated with Silastic rubber.

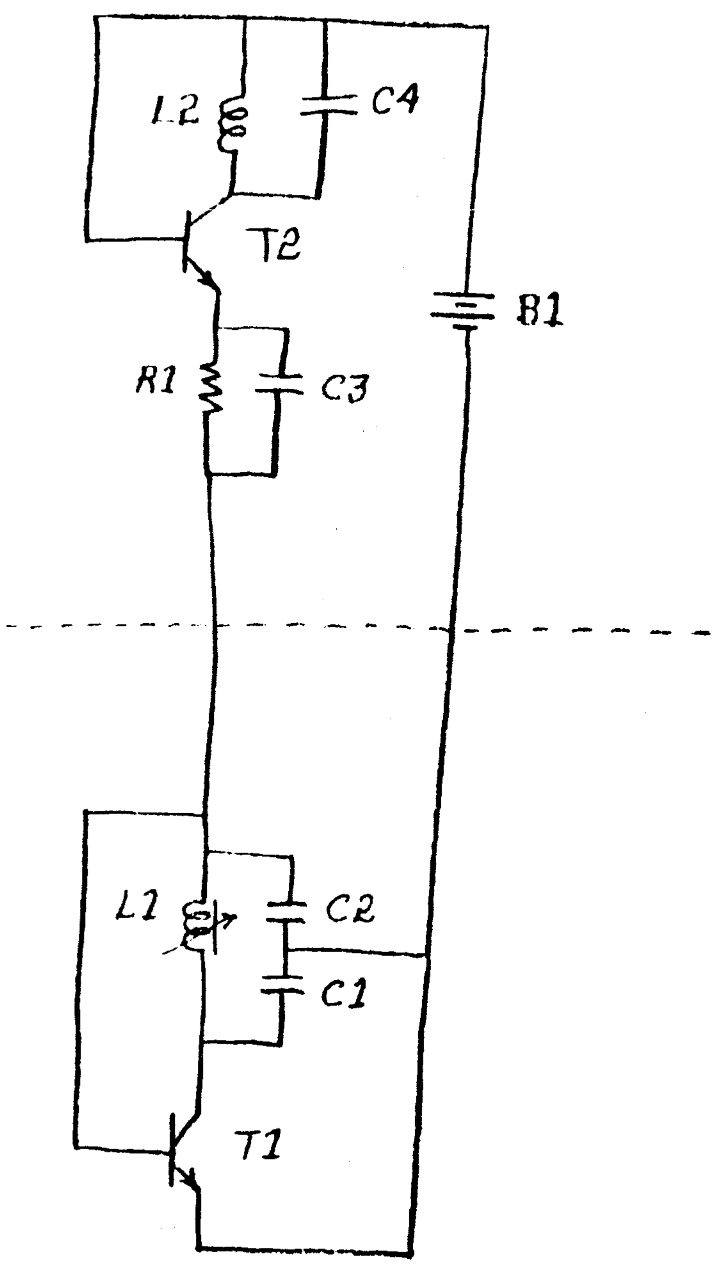
PRESSURE SENSITIVE INDUCTOR



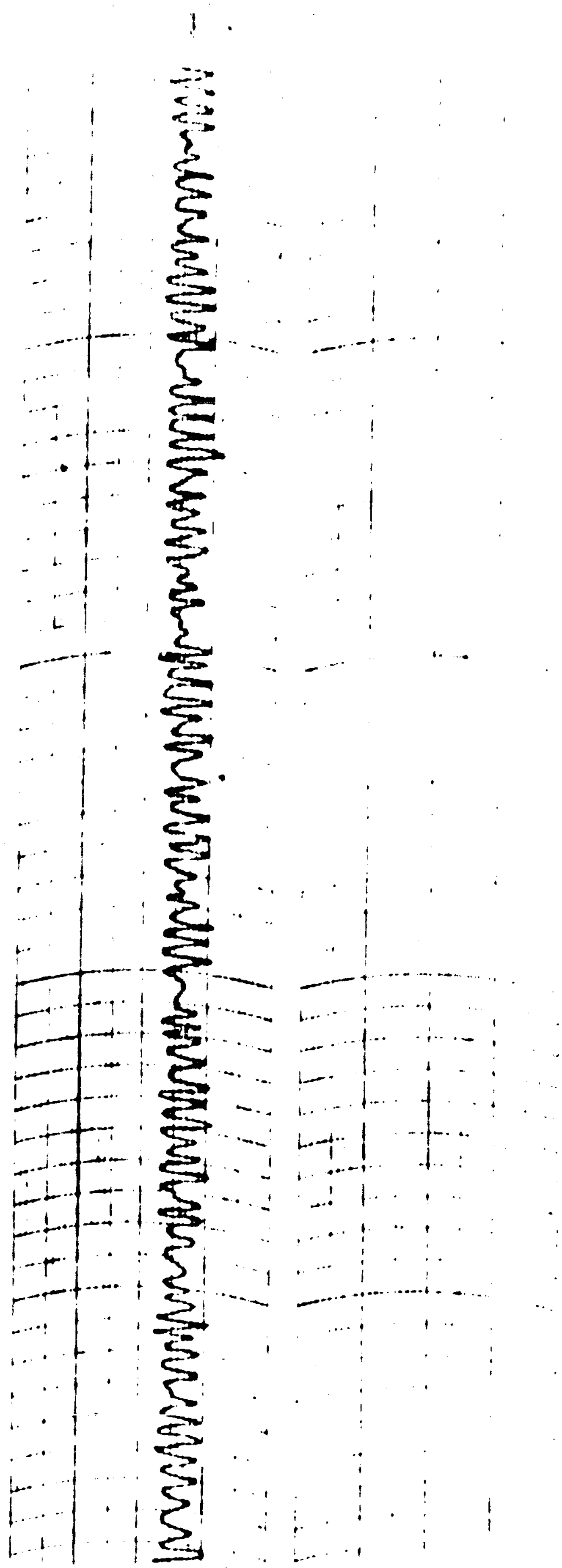


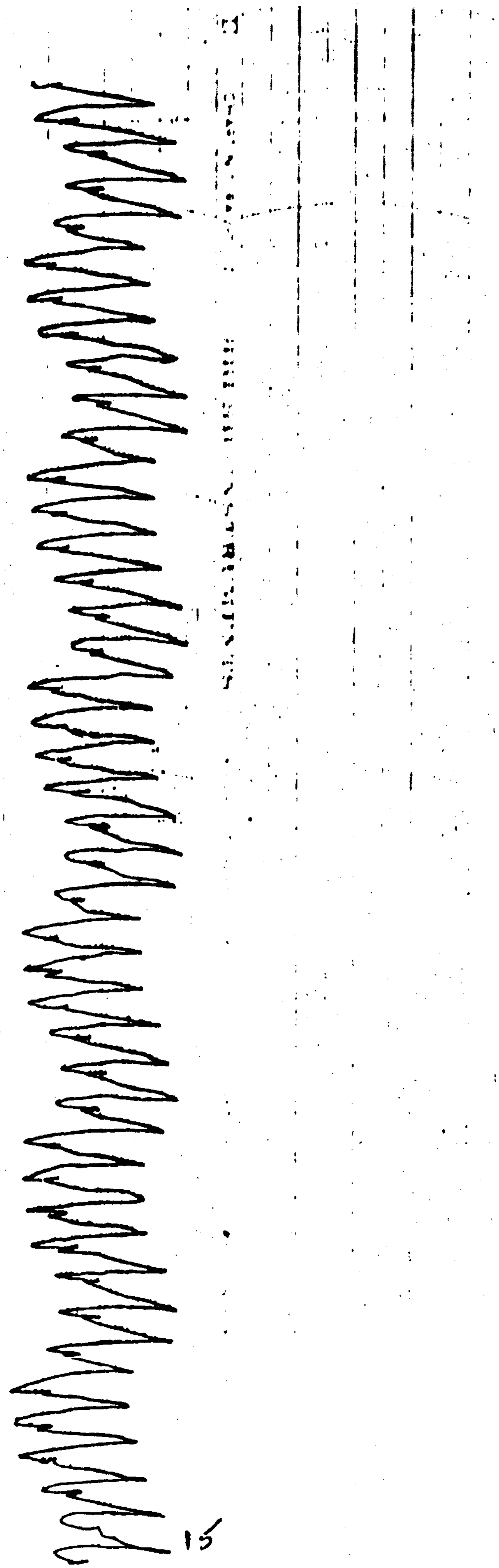
BLOOD PRESSURE SENSOR





PRESSURE
TRANSMITTER
1-15-63
D.B.




15

PARTS LIST -- PRESSURE TRANSMITTER

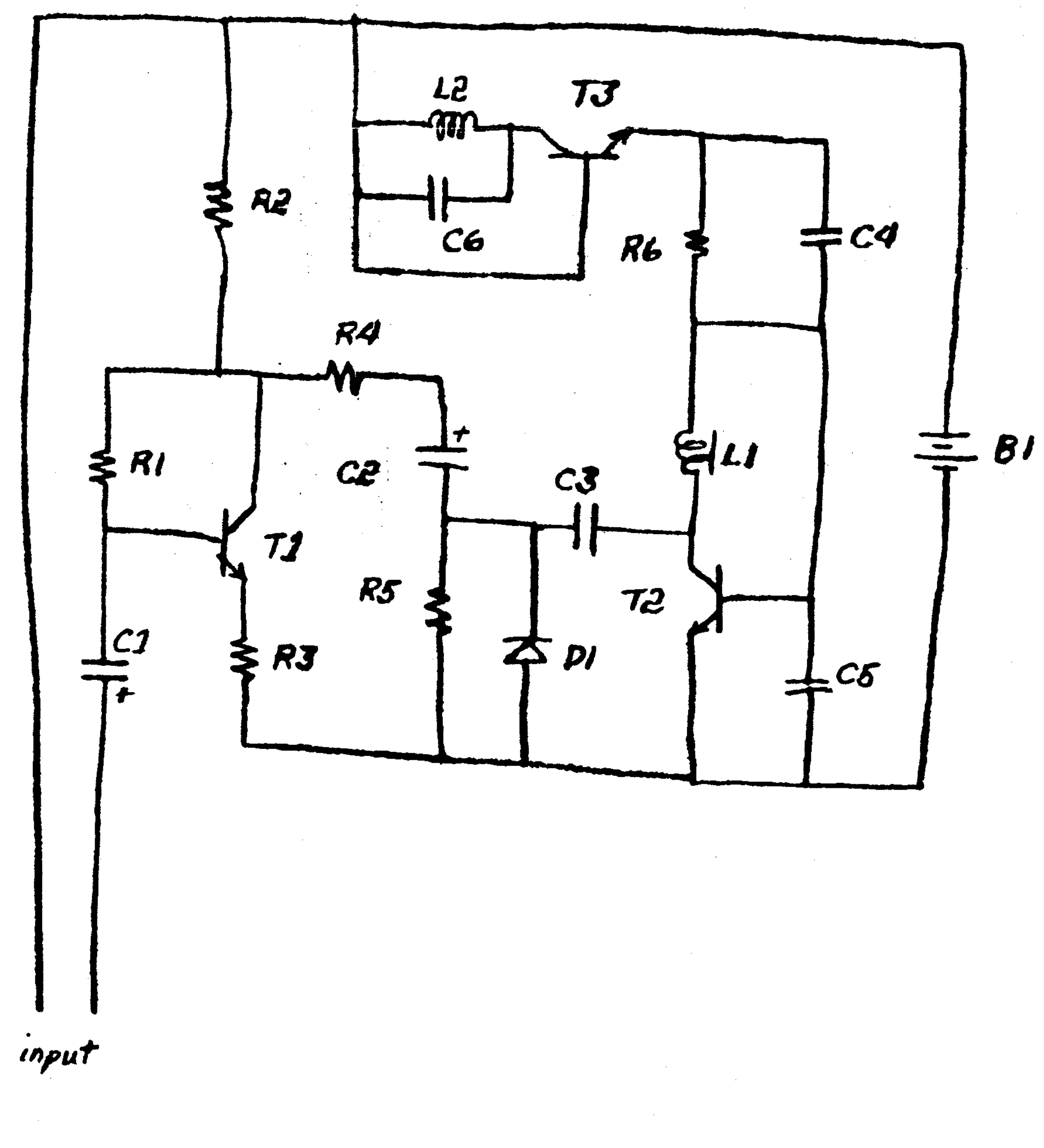
B1	battery, 1.5 volts, Hamilton No. 505
C1	capacitor, 100 pf., Vitramon No. VK21CW101
C2, 3	capacitor, 430 pf., Scionics pellet
C4	capacitor, Scionics pellet, select for maximum output
L1	inductor, pressure sensitive, see text
L2	inductor, 1100 turns No. 48, see text
R1	resistor, 200 k, C. T. S. ceradot
T1, 2	transistor, General Instrument No. MT101, select for low noise

EKG, EMG, EEG Transmitters

Electromyographic and electrocardiographic signals may be telemetered with the transmitter diagrammed in figure 10. Amplifier T1 drives the varactor diode D1 which frequency modulates the oscillator T2. T3 is a grounded base amplifier: its tank circuit (L2, C6) is tuned to the nominal oscillator frequency. Drift and instability are minimized by biasing the varactor at zero volts and isolating the closed core frequency determining inductor from the radiating inductor.

Potting is Armstrong C3 and coating is silastic rubber. Input loads are made of helical stainless steel insulated with silastic tubing. The modulation index is about 200 cps/mv and the frequency response extends from .1 to 200 cycles per second.

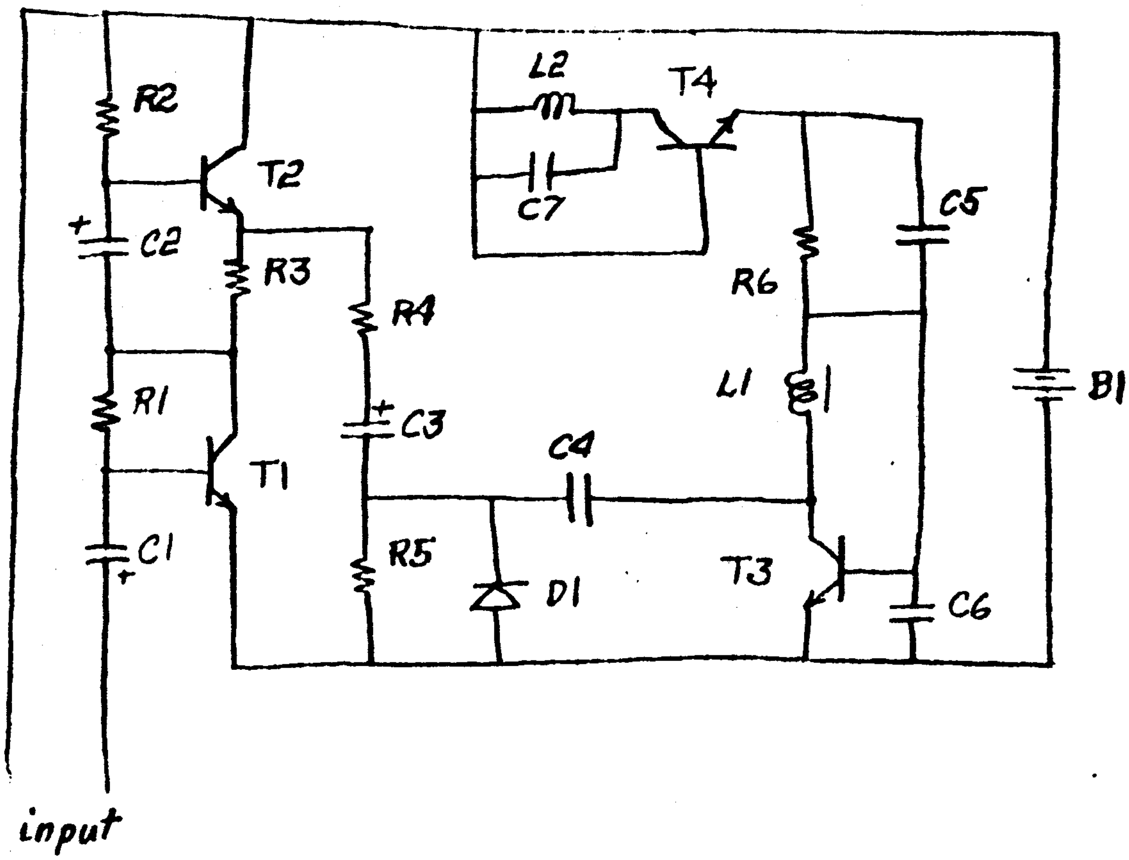
By using a higher gain amplifier stage, T1 and T2, figure 11, electroencephelograms may be telemetered. Ultra low noise (expensive) transistors must be used for the input stage; in other respects the transmitter is similar to the EKG transmitter.



EKG, EMG
TRANSMITTER
1-15-63
D.B.

PARTS LIST -- EKG, EMG TRANSMITTER

B1	battery, 1.5 volts, Hamilton No. 505
C1, 2	capacitor, 2 µtd., Sprague No. 160D27
C3, 4, 5	capacitor, 430 pf., Scionics pellet
C6	capacitor, Scionics pellet, select for maximum output
D1	varactor, Pacific Semiconductor No. V56
L1	inductor, 1500 turns No. 48, see text
L2	inductor, 600 turns No. 44, see text
R1, 5	resistor, 5 meg, Mallory No. 6928RP
R2	resistor, 1 meg, Mallory No. 6928RP
R3	resistor, 100 k, C. T. S. ceradot
R4	resistor, 500 k, C. T. S. ceradot
R6	resistor, 200 k, C. T. S. ceradot
T1, 2, 3	transistor, General Instrument No. MT 101, select for low noise



EEG
TRANSMITTER
1-15-63
D.B.

PARTS LIST -- EEG TRANSMITTER

B1	battery, 1.5 volts, Hamilton No. 505
C1, 2, 3	capacitor, 2 µtd., Sprague No. 160D27
C4, 5, 6	capacitor, 430 pf., Scionics pellet
C7	capacitor, Scionics pellet, select for maximum output
D1	varactor, Pacific Semiconductor No. V56
L1	inductor, 1500 turns No. 48, see text
L2	inductor, 600 turns No. 44, see text
R1, 2	resistor, 10 meg., custom
R3, 6	resistor, 200 k, C. T. S. ceradot
R4	resistor, 500 k, C. T. S. ceradot
R5	resistor, 5 meg., Mallory No. 6928RP
T1, 2	transistor, Fairchild No. 2N2484, molytab package
T3, 4	transistor, general Instrument No. MT101